

**PATENT APPLICATION**

**HYPERGOLIC FUEL LEAK DETECTOR AND ALARM SYSTEM,  
COLORIMETRIC WITH OPTICAL READER**

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# **HYPERGOLIC FUEL LEAK DETECTOR AND ALARM SYSTEM, COLORIMETRIC WITH OPTICAL READER**

## **CROSS-REFERENCE TO RELATED APPLICATION**

5   **[0001]**   The instant patent application claims priority from U.S. provisional patent application no. 60/425,790 filed November 12, 2002 and hereby incorporated by reference for all purposes.

## **STATEMENT AS TO RIGHTS TO INVENTIONS MADE UNDER 10           FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT**

**[0002]**   Work described herein has been developed in performance of U.S. Department of Defense contracts control nos. 700bg1082002 and 70bga762010 The United States Government may therefore have certain rights in the invention.

## **15                           BACKGROUND OF THE INVENTION**

**[0003]**   The Tactical High Altitude Area Defense (THAAD) system utilizes hypergolic fuel components which are stored adjacent to each other in preparation for use, and which operate (ignite) upon mixing. Transportation and storage of such hypergolic fuel or loaded propulsion systems require active sensing and remote alarming to a centralized area, in order  
20   to advise personnel of possible leaks. Distinguishing the presence of the hypergolic fuel components is thus desirable to promote appropriate hazardous safety response.

**[0004]**   Colorimetric (color change reagent) chemical monitors or detectors are used throughout military and commercial industry as elements of safety alarm systems. These devices are typically designed to monitor exposure over relatively short terms, such as up to  
25   eight hours. Known colorimetric systems are also normally limited to an ambient temperature range of about +/- 20 degrees.

**[0005]**   Another aspect of such conventional colorimetric detection systems is that they are typically read manually. Manual reading relies on the human eye to read and compare the color change in order to determine concentration and/or exposure levels. Using the human  
30   eye to read the amount of color change can be imprecise and subjective. Moreover, manually

read detectors can not be interfaced with area alarms to protect the safety of others, or to provide central resource response to hazardous conditions over a larger area.

[0006] Other conventional active detection systems utilize a reagent-impregnated paper tape that is slowly unreeled in front of a transmission spectrometer. However, such systems are typically bulky, consume substantial amounts of power, and do not operate over an extensive environmental temperature range.

[0007] Accordingly, there is a need in the art for methods and devices permitting detection the presence and concentration of the components of hypergolic fuel systems.

## BRIEF SUMMARY OF THE INVENTION

[0008] Embodiments of devices and methods in accordance with the present invention enable the detection and discrimination of hypergolic fuel components (derivatives of hydrazine and nitrogen tetroxide) at below 100 ppmv, to thereby provide an alarm warning before this concentration limit is exceeded as indicative of a leak in the fuel system. An embodiment of the device in accordance with the present invention is principally designed as a safety sensor to alert personnel that hypergolic materials have leaked from fuel storage containers into secondary containment. Discrimination between the hypergolic fuel components can then determine the appropriate hazardous chemical response.

[0009] Embodiments of methods and devices in accordance with the present invention may function at least over the temperature range from about -46°C to about +71°C. The detector operates by measuring a color change (colorimetric) in a substrate that has been impregnated with one or more chemical reagents. A visible detection system sends a signal to a central processing system when preset concentrations are exceeded. If these preset concentrations are exceeded, a control module activates alarm functions.

[0010] An embodiment of a transportation system in accordance with the present invention, comprises, a fuel leak detector comprising a colorimetric chemical monitor configured to change color in response to presence of a fuel, and an optical reader configured to monitor a color of the chemical monitor. An alarm system is in electronic communication with the fuel leak detector and configured to provide an alarm when a color of the chemical monitor changes by a predetermined amount.

[0011] An embodiment of a method in accordance with the present invention for detecting leakage of a hypergolic fuel system, comprises, providing a colorimetric chemical monitor, and providing an optical reader. Intensity of reflected light from the colorimetric chemical

monitor is sensed by the optical reader. An occurrence of a fuel leak is determined when the intensity of reflected light drops below a predetermined threshold.

[0012] An embodiment of a method in accordance with the present invention for identifying a fuel leak, comprises, generating a voltage based upon comparison of a reference voltage with a voltage generated by a detector receiving light reflected from the surface of a substrate impregnated with a reagent reactive with a fuel component.

[0013] These and other embodiments of the present invention, as well as its advantages and features, are described in more detail in conjunction with the text below and attached figures.

## BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Figure 1 shows a schematic view of active detection of hypergolic fuel components in accordance with an embodiment of the present invention.

[0015] Figure 2 shows a circuit diagram of electronic components of one embodiment of an active detection element of a system in accordance with the present invention.

[0016] Figure 3 shows a simplified logic diagram of an embodiment of a detection system in accordance with the present invention.

[0017] Figure 4 shows a simplified block diagram of the embodiment of a detection system shown in Figure 3.

[0018] Figure 5A shows circuit diagrams of the MON latching indicator drivers of the leak detector system of Figures 3-4.

[0019] Figure 5B shows a circuit diagram of MMH latching indicator drivers of the leak detector system of Figures 3-4.

[0020] Figure 5C shows circuit diagrams of the fault latching indicator drivers of the leak detection system of Figures 3-4.

[0021] Figure 6A shows a first portion of the controller circuit of the leak detector system of Figures 3-4.

[0022] Figure 6B shows a second portion of the controller circuit of the leak detector system of Figures 3-4.

[0023] Figure 7 shows a circuit diagram of the fault detector system of the leak detector system of Figures 3-4.

[0024] Figure 8A is a simplified flow diagram illustrating logic operation of the hypergolic leak detector of the system of Figures 3-4.

[0025] Figure 8B is a simplified flow diagram illustrating operation of electrical and test feedback systems for the hypergolic leak detector of the system Figures 3-4.

[0026] Figure 8C is a simplified flow diagram illustrating interface of the detector of the hypergolic leak detector interface with the alarm module of Figures 3-4.

[0027] Figure 9A is a perspective view of one embodiment of a leak detector in accordance with the present invention.

5 [0028] Figure 9B is a frontal view of the embodiment of a leak detector shown in Figure 9A.

## DESCRIPTION OF THE INVENTION

[0029] Embodiments in accordance with the present invention actively monitor for the  
10 presence of hypergolic fuel components, in the form of hydrazine and its derivatives, or in the form of nitrogen tetroxide and its derivatives. The detector then determines the concentration of each target compound. The presence and concentration of each chemical class is monitored by determining the change in intensity of light reflected from a surface of a reagent-impregnated target. The greater the color change due to reaction between the  
15 reagents and the target compounds, the greater the absorption of light and the reduction in observed reflected light.

[0030] In accordance with one embodiment of the present invention, chemical reagents of interest are adsorbed onto a porous element of the detector. In accordance with one embodiment of the present invention, the porous element comprises a disc formed from  
20 Whatman No. 4 grade filter paper. Mercurous chloride/methylcellulose reagent may be adsorbed into one region of the paper disc. N-phenylanthranilic acid/titanium dioxide reagent may be adsorbed into another region of the paper disc.

[0031] The mercurous chloride/methylcellulose reagent present in the detector element may react selectively with monomethylhydrazine (MMH) and its derivatives to effect a color  
25 change from white to black. The magnitude of this color change is proportional to the extent of reaction between the reagent and the hypergolic fuel component.

[0032] Similarly, N-phenylanthranilic acid/titanium dioxide reagent present in the detector element may react selectively with mixed oxides of nitrogen (MON) such as nitrogen tetroxide and its derivatives, to effect a color change from white to yellow. Again the  
30 magnitude of this color change is also proportional to the extent of reaction between the reagent and the hypergolic fuel component.

[0033] Integrating the target compounds in the colorimetric sensor may increase the sensitivity of the detector. The chemical reagents impregnating the disk will fully react with any target chemical species that contact the reagent, with virtually no reverse reaction. When

the reagent has reacted, the color will be fully changed. Such a color change will occur either if a slow leak occurs over a long period, or if a fast leak occurs more rapidly.

**[0034]** The active portion of the detector element analyzes the extent of color change of the colorimetric detector, and then calculates concentration of the relevant fuel components

5 through comparison to a predetermined detector reference voltage. In accordance with one embodiment of the present invention, the active portion of the detector element may use blue light having a wavelength of about 450 nm from a light emitting diode (LED) to measure fuel component concentration.

**[0035]** As shown in the simplified schematic view of Figure 1, light 100 transmitted from  
10 LED 102 is split into two paths 100a and 100b. One path 100a reflects off of first portion 104a of surface of the reagent-impregnated porous detector element 104, passing through first optical notch filter 106a onto first silicon optical detector 108a. First optical detector 108a is in electronic communication with first comparator 109a.

**[0036]** Second light path 100b reflects off of second portion 104b of the surface of the  
15 reagent-impregnated porous detector element 104, passing through second optical notch filter 106b onto second silicon optical detector 108b. Second optical detector 108b is in electronic communication with second comparator 109b. Both first and second comparators 109a-b are in electrical communication with predetermined reference voltage  $V_R$ .

**[0037]** Initially, when no hypergolic fuel components are present, light reflected from the  
20 surface of the porous detector element causes detectors 108a-b to output a voltage equal to  $V_R$ . Subsequently, when one or more hypergolic fuel components are present, one or both of the reagents experiences a color change. Light is correspondingly absorbed at the surface of the detector element, reducing the amount of light reaching the respective detector 108a-b. In response, the relevant detector elements 108a or 108b output a reduced voltage. Comparators  
25 109a-b in turn output an increased voltage to a control module (not shown in Figure 1).

**[0038]** When the reference voltage is matched or exceeded by the voltage output from the detector, the control module in turn sends a signal to the central alarm module. Voltage from the detector is a measure of the extent of the chemical reaction occurring on the reagent-impregnated disks of the detector. It will take approximately 0.5 milligrams of fuel or  
30 oxidizer to fully react with the chemical reagent to result in a full color change that results in the signal exceeding the reference voltage.

**[0039]** Figure 2 shows a circuit schematic of the electronics of the detector element. Blue light emitted from diode D1 is reflected off of the surface of the impregnated porous material. Photodiode D2 receives light reflected from the surface of the portion of the disc impregnated

with mercurous chloride/methylcellulose reagent. Photodiode D3 receives light reflected from the surface of the portion of the disc impregnated with N-phenylanthranilic acid/titanium dioxide reagent.

[0040] The resulting voltage from diodes D2 and D3 is communicated to nodes 3 and 12 of comparators U3A and U3D respectively. A reference voltage of +2.5 V is supplied to second nodes 2 and 13 of comparators U3A and U3D respectively.

[0041] Deviation of the voltage received at the first nodes, from the reference voltage received at the second nodes, in turn results in generation of an output voltage of comparators U3A and U3D. This output voltage can then be sensed to indicate the presence of one or both of the hypergolic fuel components.

[0042] The performance of optical components, typically a light-emitting diode (LED) light source as well as of electronic components, may be affected by temperature. Through selection of components with characteristic positive and negative temperature coefficients, the effect of temperature upon performance can be minimized, resulting in a voltage signal vs. temperature slope of about zero. Minimizing the temperature effect allows the detection threshold to be reduced. A lower detection threshold in turn reduces the time for detection and increases the sensitivity of the device. Passive compensation for temperature effects simplifies the architecture of the device, reduces power consumption, and enhances the robustness of the device in a variety of environments.

[0043] Figure 3 illustrates a simplified logic diagram of one embodiment of a detector system in accordance with the present invention. Figure 4 illustrates a simplified Block Diagram of the detector system of Figure 3.

[0044] Figure 5A shows circuit diagrams of the MON latching indicator drivers of the leak detector. Figure 5B shows circuit diagrams of the fault latching indicator drivers of the leak detectors. Figure 5C shows a circuit diagram of MMH latching indicator drivers of the leak detector.

[0045] Figure 6A shows a first portion of the controller circuit of the leak detector. Figure 6B shows a second portion of the controller circuit of the leak detector.

[0046] The control module monitors the detector system and activates an alarm module once the detector response exceeds a preset value. The control module also includes a central control and alarm, conditions power from station power (120/240 VAC or battery), collects detector output. In embodiments featuring multiple detector heads, the control module sequences power to each detector head.

[0047] The controller circuit provides a remote alarm and provides alarm alerts to area personnel specific to the fuel component leaking. The controller circuit also provides lapse time from alarm condition, nonvolatile fault and alarm indication, and 60 minutes of audio and visual alarm.

5 [0048] The control module also checks for operational conditions of each detector head. Figure 7 shows a circuit diagram of the fault detection system of the leak detector.

[0049] Figure 8A provides a simplified flow chart of the overall logic for the embodiment of the detector system just described. Figure 8B provides a simplified flow chart of the logic for electrical test and feedback systems of the detector. Figure 8C provides a simplified flow  
10 chart of the logic for interface with an alarm module.

[0050] Figure 9A is a perspective view of one embodiment of an optical detector head in accordance with the present invention. The detection head 900 is connected via umbilical cord 902 to control panel 904 shown in perspective view in Figure 9B. In an embodiment in accordance with the present invention, up to eight detector heads can be connected and  
15 controlled by the control panel utilizing standard military connectors and cabling.

[0051] The front view of the control panel illustrated in Figure 9B. shows eight section panels 912 each having three latching indicators 914, one each for MMH, MON, and for fault. Control panel 900 further includes power switch 902 and power indicator light 904, and also includes test/reset switch 906. Control panel 900 also includes speaker 908 that  
20 serves as an audio indicator for an alarm event. Control panel 900 further includes timer 910 indicating the time from the last detected incident. Switches 916 and 918 may be employed to momentarily stop the alarm visual and audio alerts, or to acknowledge and turn off the visual and audio alarms.

[0052] While the above is a full description of specific embodiments in accordance with the  
25 present invention, various modifications, alternative constructions and equivalents may be used. For example, multiple detectors can be controlled and monitored by the system. In accordance with one embodiment of the present invention, a common control panel could be used to monitor leakage both optically and electrochemically.

[0053] Embodiments in accordance with the present invention offer a number of  
30 advantages over conventional detection systems. One such advantage is substantially reduced power consumption. Embodiments in accordance with the present invention may be operated on battery or station power, at 120/220 VAC. Embodiments may operate on extremely low power, for example at less than about 1 milliamps at 5 VDC. Battery operation can thus last for more than 30 days using a 7.5 amp hour battery.



[0054] Power conservation techniques that may be employed by systems in accordance with embodiments of the present invention include use of latching indicators and relays to require the pulsing of power only during transitions. CMOS circuitry may also be used to minimize current drain. In embodiments featuring multiple reader heads, power may be  
5 sequenced to each detector head at a low duty cycle in order to conserve power.

[0055] Other advantages of embodiments of methods and systems in accordance with the present invention include light weight and relatively small size. There are no known colorimetric detector systems of this size, owing in part to avoidance of the need for mechanical devices to unroll and then store as unrolled paper to serve as a record of past  
10 detected levels.

[0056] Still another advantage is the relatively simple architecture of the detection system, which increases its robustness and extends its environmental operation range. As illustrated by Figures 8B-C, the system also includes built-in testing for power and detector output.

[0057] Another advantage offered by embodiments of colorimetric detection devices in  
15 accordance with the present invention is the long-term stability of the chemical reagents used as part of the detector. The relative inertness and stability of these reagents in absence of hypergolic fuel components allows active monitoring using color change over an extended period and over a wide range of temperature and environmental conditions expected to be encountered in military applications such as THAAD as well as non-military applications.

[0058] While the above-described system is principally designed to operate as a safety  
20 sensor for THAAD missile system to meet US transportation safety requirements, additional uses of the sensor system could include any propulsion systems in civilian and military rocket launch systems, satellite systems, and military munitions that utilize hypergolic or other fuels. The manufacture, transportation, and storage of hypergolic fuels could also utilize this  
25 technology to ensure safe operations.

[0059] Given the above detailed description of the present invention and the variety of embodiments described therein, these equivalents and alternatives along with the understood obvious changes and modifications are intended to be included within the scope of the present invention.